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The construction and testing of these two cloud simulation chamber facilities, with precise wall temperature control, is described and discussed.

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CONSTRUCTION OF UNIVERSITY OF MISSOURI-ROLLA'S

FULL SCALE CLOUD SIMULATION CHAMBER AND APPLIED RESEARCH

FINAL REPORT

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U.S. ARMY RESEARCH OFFICE

AFOSR F49620-80-C-0090

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Statement of Purpose

The purpose of this work is to construct two cooled wall cloud simulation chambers. The smaller 48-inch tall chamber capable of being cooled at 10°C/min and the larger 112-inch tall chamber capable of 15°C/min. Construction will include such support peripherals as secondary cooling, computer control, data acquisition, and other systems required for the operation of the chambers. The chambers will be incorporated into the existing ~~UMR~~ Univ. of Mo., Rolla, cloud simulation facility.

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INTRODUCTION

During the contract period work has been performed on three different cooled wall expansion cloud chambers. Initially scientific studies were to be carried out using the original chamber (Proto I) while construction of the larger new chamber (Romulus) was under way. Early in the work it was determined that Proto I as it then existed could not be effectively used for any further studies, and a decision was made to abandon it. At the same time it was decided to use as much equipment as possible from Proto I and build an improved version (Proto II) using the same basic dimensions.

Proto II is currently operational and the Romulus chamber is mechanically ready for operation in a 48 inch tall configuration. Work on the temperature sensing and control system for the Romulus chamber is continuing with materials already on hand.

The operational response of the Proto II chamber has been as good or better than originally estimated in terms of wall control. There is every reason to believe the Romulus chamber will be as successful.

PROTO I CHAMBER

The initial intent was to utilize the then existing Proto I cooled wall cloud chamber to conduct some of the simpler scientific studies while the larger more versatile Romulus chamber was under construction. Also any additional engineering data concerning chamber operating characteristics would be used to improve the Romulus design.

The Proto I chamber was a 10 sided right cylinder with a nominal inside diameter of 18 inches and an interior height of 24 inches. Wall construction consisted of a segmented inner wall of 0.25 inch thick black hard anodized aluminum plates held to 3 inch thick aluminum outer walls by a matrix of studs screwed into blind holes in the inner wall plates and extending through the outer walls. Thermoelectric cooling modules (TEM's) were clamped in the region between the inner and outer walls and used to control the temperature of the inner wall by pumping heat between it and the outer wall as required. Liquid cooling passages in the outer wall plates regulated their temperature permitting them to act as heat sinks for the TEM's.

The outer walls consisted of circular plates for the top and bottom sections with the side walls made in 10 separate pieces which were bolted together. In practice this design presented several problems with chamber sealing and temperature uniformity.

The electrical grouping and control of the individual TEM's varied over the life of the chamber beginning with a single temperature control sensor in the chamber inner wall and all the TEM's wired in series to a single programmable analog power supply. This severely limited the maximum cooling rates to typically less than 1°C/min. Later work grouped the TEM's into 28 sets, with the TEM's of each set wired in series and the sets in parallel to a single high power programmable supply. This increased attainable cooling rates but degraded chamber temperature uniformity due to variations in response of the different sets of TEM's. The final configuration utilized a separate temperature sensor, analog control circuit and programmable power supply for each of the 28 sets of TEM's. This provided the best combination of temperature uniformity and maximum cooling rate of 10°C/min.

As the Proto I chamber was pushed to larger expansions and faster cooling rates several problems surfaced. The large (2 inch diameter) uncooled sample ports in the center of both the top and bottom plates of the chamber created a continuous updraft through the central viewing volume. Several attempts were made to provide active temperature control for the interior surfaces of the ports with little, if any, success. In addition to the motion imparted to the cloud, the local heating indicated by the updraft immediately cast doubt on the accuracy of our knowledge of the environmental parameters of the sample being studied.

The problem of the uncooled sample ports might have been dealt with, however the failure of several sections of thermoelectric cooling modules (TEM's) as the chamber was operated at higher cooling rates began to make temperature control of the interior wall surface a very questionable. Analysis of the apparent causes and effects seemed to indicate that the silicone potting compound which had been used to encapsulate the TEM's during the early attempts to seal the chamber was mechanically tearing the TEM's apart as it expanded due to heating interval in TEM's I^2R loses when operated at high power levels. Inspection of the damaged sections during disassembly of the Proto I chamber verified this analysis.

Late in the first year of the project the decision was made to abandon any further attempts to utilize the Proto I chamber. At the same time it was decided to use the parts on hand for a second set of sidewall plates to build an improved version of the Proto I chamber (Proto II) and incorporate as many of the improvements planned for the Romulus chamber as feasible. The new chamber would provide experience with some of the new techniques on a smaller scale before they were applied to the Romulus chamber. An example was the decision to use the new programmable switching power supplies being designed and built for Romulus, but to remain with the analog type control system of Proto I instead of the digital control planned for use with the Romulus chamber. Also it was felt that the new chamber would prove scientificly useful in its own right with a shorter construction time, lower operating costs and the segmented sidewall design permitting the more efficient modification to accommodate specialized ports or equipment for individual experiments.

PROTO II CHAMBER

Once the decision to rebuild the prototype chamber was made design modifications were considered in order to correct the problems encountered with the Proto I chamber. It should be kept in mind that the basic cooled wall design consists of thermoelectric cooling modules (TEM's) sandwiched between a relatively thin inner wall and a thick outer wall which acts as a liquid thermostated heat sink as well as a structural chamber wall. Temperature control of the interior chamber surface is maintained by using the TEM's to pump heat between the inner wall and the outer heat sink as required.

The problem of the uncooled sample ports located in the center of the top and bottom plates was solved in a relatively straight-forward manner. The single large port in each of the two plates was replaced by a large number (164) of small ports distributed over the entire interior surface of the plate. These ports are sufficiently small that they can be located in the area between TEM's (which also provides space for the studs used to clamp the inner wall and the heat sink together). This allows the TEM's to be laid out in a uniform pattern over the entire surface of the plate.

Lines from the small individual ports are collected at either the inlet manifold (top plate) or the outlet manifold (bottom plate). The manifolds also contain the actual inlet and outlet valves and are part of the expansion volume when the chamber is operating. The distributed inlet-outlet system also has the additional advantage of helping to insure a uniform flushing of the chamber during cleaning or sample introduction.

Since the change in inlet-outlet port design required remaking the top and bottom heat sinks, this opportunity was used to alter the overall shape from circular to rectangular. Experience with the Proto I chamber had shown that trying to cool only that part of the top or bottom plate surface which was inside the expansion volume resulted in uncooled corners where the top and bottom met the side walls. The modified design provided for cooling the entire surface of the top and bottom plates so that the cooled inner wall plates extended beyond the junction with the side walls. This proved to produce a more uniform temperature across the interior surface of the top and bottom and standardized both the shape of the inner wall plates and TEM configuration.

The second major change involved the elimination of the silicone potting compound from the region of the TEM's. Experience with the Proto I chamber had shown that the use of a stud on all four sides of every TEM as recommended by the supplier represented an unnecessary overdesign for our application. By reconfiguring a reduced number of studs it was possible to remove them from the area along the edge of the plate. This then permitted the use of a gasket to seal around the TEM's, and between the inner wall plate and the heat sink.

Preliminary design work for the Romulus chamber had developed an improved design for the inner wall plate. This consisted of using a sheet of adhesive to bond two aluminum plates into a single composite plate, and provided several advantages. First the increased thermal resistance of the thin adhesive bond restricted heat flow and produced an enhanced smoothing effect on the temperature profiles across the interior face of the plate. The smoothing is required because of the nonuniform removal of heat from the plate, which in turn arises from the fact that the 32 individual TEM's under a single plate do not touch each other. Analysis indicated the laminated design should provide the same smoothing effect as a solid aluminum plate one inch thick but without the unweildy thermal mass (heat capacity) of the thick plate. The design also permits the use of inserts to increase the length of thread engagement between the plate and studs; this had been a minor problem with the Proto I chamber.

As a final test of the design, a test plate using the new design was constructed and mounted on one of the sidewall heat sink sections from the Proto I chamber which had been modified to accept the altered stud pattern. A series of cooling tests using sheets of temperature sensitive liquid crystals was performed and verified that the laminated design would provide adequate temperature smoothing across the gap between individual TEM's at the highest cooling rates. The test results showed that while adequate smoothing was achieved across the gap between TEM's, the removal of the silicone potting compound had reduced the reverse heat flow from the heat sink to the inner wall plate and revealed an overall temperature nonuniformity along both axes of the rectangular plates. When this was discovered a more extensive series of tests using surface transistor thermometer sensors was undertaken to determine both the source of the problem and a solution.

As data was collected it became apparent that at least two different effects were being observed. The first was the overall temperature variation where the edges of the plate cooled slower than its central region. This effect was noted to be dependent on the cooling rate with differences increasing for faster cooling rates. Further studies were carried out to insure that the effect was not due to nununiformities in the heat sink temperature or interaction with adjacent inner wall plates. It was finally concluded that this particular effect was due to variations in the amount of inner wall plate cooled by the TEM's in the center of the 4 by 8 array compared to that cooled by those along the edge. After several months of study and testing it was determined that since the locations of the TEM's within the array were such a basic factor in the overall design any significant movement of their location was not feasible; therefore the excess material associated with the outer TEM's should be eliminated by a shallow bevel around the edge of the plate on the interior face. This proved to be a satisfactory solution.

During these tests a second effect was discovered in which the plate temperature measured over adjacent TEM's varied in what appeared to be a random manner. While measurements were repeatable for a given assembly, there was no observable correlation with location on the plate or from one plate and TEM set to the next. Again after several months of study the effect was traced to variations in the cooling efficiency of individual TEM's due to variations in the clamping force applied to them. These force variations were then traced to small differences in the heights of adjacent TEM's under the same inner wall plate.

Tests showed that excellent temperature uniformity would be secured by requiring all TEM's purchased to be the same height to within the 0.0001 inch tolerance or less. This however was a probibitively expensive solution to the problem. However, the large number (7500+) of TEM's required did permit specifying a realistic height tolerance of $\pm$ 0.002 inches. Then the units would be grouped into sets with the closer tolerance for use under a single plate. Plate-to-plate height variations had no measurable effect on temperature.

To measure the large number of TEMs a semiautomated gaging station was developed. As each unit was placed in the gaging jig and the measuring head brought down against it, the NOVA 840 control computer read 5 precision linear position transducers, calculated the effective thickness and stored the results together with the unit serial number. Once all the units had been measured, a processing program was used to select those sets of TEM's with matched heights to be used under each individual plate. Once selected the program automatically removed a unit from the source file to prevent selection for use in more than one set.

The completion of the tests on wall temperature uniformity together with TEM specification, purchasing and gaging took place during the latter half of the second year of the project. Final temperature tests optimized the bevel design. Approximately the same time machining of the new top and bottom heat sinks was completed. The heat sinks for the first side wall ring were also ready. Lamination of the inner wall plates for the Proto II chamber was started once acceptable solutions to the temperature uniformity problems had been determined. Machining of the second set of side wall heat sinks was also started.

The extensive manifolding required for both the secondary cooling (heat sink liquid flow) and expansion systems of the Romulus chamber had led us to investigate the use of molded polymer parts. Unfortunately while the quantities required were large enough to preclude individual machining from solid or standard shapes, they were not large enough interest outside vendors. Therefore we used fiberglass reinforced casting epoxy, which permitted the use of relatively simple open molds and which could be handled by student workers. During the first half of the second year molds for the cooling manifolds needed on the Proto II chamber were developed and production started. The manifolds were ready at the time the heat sinks were complete in the latter half of the second year. This permitted the system to be assembled and leak tested.

Temperature uniformity tests also demonstrated that rather tight restrictions had to be imposed on the thermal conductivity in the sealing gasket between the inner wall plate and the heat sink. In earlier work a gasket molded from a RTV silicone rubber had been developed which provided an acceptable seal; however the high thermal conductivity caused an unacceptable increase in plate temperature around the edges. Various inhouse procedures were tested. We found no external supplier willing to develop a gasket with the required sealing and thermal characteristics. Finally near the middle of the second year an inhouse procedure using a foam in place polymer (Eccofoam-Sil by Emerson & Cumings) was developed which did produce an acceptable gasket. The procedure was slow and produced a high number of rejects, but it premitted the overall work to proceed.

During the third year fabrication of the inner wall plates for the Proto II chamber including the beveling and black hard coat anodizing was completed. After the first set of plates was ready, and sufficient sets of TEM's had been selected and electrically wired into series sets, the inner wall plates, TEM's, and gaskets were assembled and fastened to the top and bottom heat sinks and one set of side wall heat sinks. The sections were then assembled in their final configuration for a 24 inch tall chamber. Once the individual sections had been assembled as a chamber, work on the final design and testing of the intersectional seals was initiated. The final design uses a combination of O-ring cord and RTV silicone rubber to seal between the individual side wall sections and a gasket cut from a closed cell polyurethane foam sheet to seal between the side walls and both the top and bottom sections. The grooves formed by the beveling of the inner wall plates on the top and bottom sections were filled with the RTV where they meet the side wall sections, providing a level surface for the gasket to seal against.

With the basic parts for the Proto II chamber assembled, final design, construction and installation of both the sample inlet-outlet system and the secondary cooling system could be carried out. At the same time parts from the Proto I chamber were modified for the external plumbing of the expansion system and installed on the Proto II chamber. Final layout of these systems had been delayed until this time due to the close interweaving of their physical locations. Coordination of their layout greatly simplified the overall task.

While work continued on the 24 inch version of the chamber, machining, lapping of the TEM mounting surface, and anodizing of the second set of side wall heat sinks was completed. The remaining sets of TEM's required for these sections were selected and prewired for mounting together with the finished inner wall plates. It was at this point, approximately midway through the third year, that we tried to order additional Eccofoam-Sil for the additional gaskets required and were informed that production had been permanently discontinued. This meant that an immediate search for a substitute material and/or gasket design had to be initiated which continued into the early part of the fourth year. At this time an outside vendor was found who was willing and able to supply die-cut sponge gaskets with the required sealing and thermal characteristics in the quantities needed (and for a reasonable price).

During the third year we reorganized and enlarged the control and data acquisition equipment console to provide additional space for equipment for the Romulus chamber. The reorganization was also used to group the equipment for the Proto II chamber into a single logical grouping.

Near the end of the third year work on the cabinets and wireways for the main TEM power supplies and wiring had reached the point that the main power leads could be run to the Proto II chamber. A series of thermal response tests were performed to collect design data for use in designing the analog controllers for the Proto II wall temperature control. Initial results indicated the need to design several different controller circuits for use with different areas of the chamber wall. We preferred to have a single design which could work on any control section of the chamber; therefore an investigation of the cause of the variations was initiated and fortunately the problem turned out to be very simple. The differences all occurred on the top and bottom sections and were traced to variations in the heat load transferred from the side wall heat sinks to the top and bottom section inner wall plates where they meet at the gasket seal. The simple solution consisted of increasing the thickness of the gasket and hence its thermal resistance. This was carried out and a single controller design became feasible for all control points.

Early in the fourth year the Proto II chamber was disassembled so that openings for the windows could be machined in three of the side wall sections. At the same time the Eccofoam-Sil gaskets were replaced with the new sponge gaskets and the chamber reassembled in the 24 inch configuration. The pressure transducer and electronics from the Proto I chamber were mounted, calibrated and tested. The digital expansion valve was used during the final chamber pressure tests to verify the seals.

Construction of the three cooled windows for the Proto II chamber was completed and the windows installed. Additional pressure tests showed the windows to be sealed. Open loop temperature tests of the windows demonstrated that they were capable of cooling rates as high as the maximum for the chamber. Once the windows were installed the optical systems from the Proto I chamber were modified and reassembled. The flash photography system was further modified so that it uses the same lamp and energy storage system as for the Romulus chamber.

By the middle of the fourth year the computer software developed for the NOVA 840 control and data acquisition computer had been converted from the Proto I chamber to the Proto II chamber. Modification of the primary analysis and data print out programs was also completed and tested. The computer cloud model used for generating the temperature and pressure vs time profile necessary for chamber control was transferred from the university's central main frame computer to the Center's NOVA 3 minicomputer. This provides a faster turn-around when additional profiles are needed and with the data link between the NOVA 3 and

840 the files can be transferred directly between computers. The latter point became particularily important when the size of the profile matrix was increased from 3 x 121 to 3 x 1001 elements.

As the fourth year ended and the fifth year began, construction and installation of the wall temperature controllers was completed. Thermometer sensors were constructed and calibrated to operate the 40 control points of the 24 inch chamber and enough programmable switching power supplies were finished to power the required TEM's. The required safety and emergency shut down circuits for the power supplies had been installed. The zero and gain of the individual wall temperature controllers had been set prior to their installation and all was ready for the operational tests of the Proto II chamber.

In order to limit power dissipation during the tests, only one transformer was turned on at a time. The 24 inch chamber requires two of the nine power transformers. When the first full set of 10 power supplies were turned on together it was found that the system had sufficient noise in the control loop to cause stability problems. The search for the source of the noise disclosed several undocumented grounds in the computer data acquisition circuity which produced ground loop paths between the controllers, power supplies and thermometers. Since removal of those grounds in the computer would involve extensive development and construction time, optical isolation units were added to the individual controller boards to provide isolation in the signal line between the controllers and power supplies and thereby break the ground loops. This modification improved the operation of the chamber significantly, but it was still unstable.

In trying to analyze the problem even after several additional sources of ground loops were located and eliminated it was obvious that we were still dealing with several simultaneous causes-effect pairs which confounded solutions to the problems. The first cause and effect to be isolated was a quasi-periodic offset in a thermometer reading followed by a return to the initial reading. The cause was finally traced to an interaction between the RF noise produced by the high frequency switching power supplies and the closed loop time constant of the control system. Slowing the response time of the power supplies alleviated the problem without degrading the operation of the system.

A second problem was traced to certain individual thermometer sensors which became noisy when exposed to the RF environment which was generated by the surrounding TEM's being driven by the switching power supplies. These sensors were replaed or used in less critical and quieter locations.

A third problem was traced to the reference voltage power supplies within the transistor thermometer electronics. These voltages were showing shifts and spikes in response not only to the RF of the switching power supplies, but also due to interaction with other equipment such as the A/D system of the data acquisition computer. This problem required redesigning and rebuilding the affected power supplies as well as noise hardening other electronics within the thermometry system.

The fourth problem proved to be the most formidible to trace but the simplest to remedy once the source was isolated. The effect was a change in the thermometer readings which appeared to have some correlation with the total power level of the switching power supplies when they were operating at high levels. The effect of a particular power supply operating at high power varied from one control loop to another. The problem was finally traced to the transistor thermometer sensors acting as diodes and rectifying the RF noise from the switching power supplies. The effect had a positive feedback component since the offset in thermometer reading caused the power supply to increase power to bring the reading back to the set point which in turn caused a further change in the thermometer reading. A simple filter capacitor across the sensor leads proved an effective solution. At this point the chamber control was acceptable and operational tests could be continued.

Operational Tests of Proto II

Pressure Control - The first areas tested once the Proto II chamber became operational were the pressure and wall temperature controls. The pressure transducer was recalibrated using the two precision ($\pm$0.01%) dead weight pressure gauges. One of the dead weight gauges is also used to provide a stable reference pressure for the differential transducer during operation. The resolution of the pressure measuring system is one part in 10^4 with an accuracy of 5 parts in 10^4. During normal operation the pressure transducer voltage is read by the computer using a 16-bit high speed A/D and the pressure is then calculated from a least squares polynominal fit to the calibration data. (The current fit is a cubic.) The system reads the pressure and recalculates the required setting of the digital valve once each second and is capable of recovering from any abrupt but continuous changes in desired pressure within approximately two update periods. The RMS pressure error for a linear expansion of 5°C/min cooling rate is typically 0.004 psi and 0.0095 psi for 10°C/min. In both cases the error includes the transition from the initial constant pressure mode to full expansion; thence from full expansion to a constant pressure mode at the final desired pressure.

Wall Temperature Control - Settling time for the response of the wall temperature control to a step change of 1°C in the desired temperature is approximately 30 seconds. RMS value of the error of the 39 measured wall temperatures about their mean is normally less than 0.05°C and typically less than 0.025°C when the system is controlling at a constant temperature. The spread in wall temperature does increase when the chamber is undergoing changes in temperature due to variations in the response of the individual control loops. The error in mean chamber temperature compared to the desired temperature can be as much as 0.35°C during the transition from a constant temperature mode to a maximum cooling rate of 10°C/min due to the thermal inertia of the walls. A similar overshoot is observed following the transition from cooling to constant temperature mode at the end of a typical expansion. After the initial transient overshoot the offset typically reduces to less than 0.125°C with smaller offsets for slower cooling rates. Observed temperature fluctuations for a single temperature sensor as a function of time are normally less than 0.005°C and typically 0.002°C over a 5 minute period.

Initial tests of dynamic response show that the chamber is capable of following a sinusoidal temperature input of 1°C peak to peak amplitude and 60 second period. A trade-off is possible between the amplitude and period. All of the above results are in response to control profiles used just as they come from the computer cloud model. As reported below, improvement in temperature control is possible by correcting the profiles to account for the thermal inertia of the walls.

Initial Cloud-Forming Expansions - The first cloud forming expansions with the Proto II chamber involved the use of 0.05 micron diameter NaCl monodispersed aerosol as cloud condensation nuclei (CCN). Initial results were somewhat variable when compared to the cloud model predictions. Comparison of the actual cloud arrival time to that predicted showed very little repeatability. This problem was traced to alteration of the initial vapor content of the chamber by the polymer tubing used in the sample inlet and outlet system. This tubing has been replaced by a fluorocarbon tubing which does not absorb moisture.

The stability of the cloud formed seemed, as one would anticipate, to have a definite correlation with the degree of agreement between the actual aerosol concentration in the chamber and the concentration assumed in the generation of the control profile.

During these tests the 4° Mie scattering system from the Proto I chamber had been used to observe the droplet growth. The drops can normally be tracked from approximately 0.7 micron radius to about 12-15 micron radius. The upper limit varies because it is limited more by chamber turbulance than drop growth effects. One particularly stable cloud permitted following the drop growth to 20 micron radius.

Dry Expansions - During the last six months of the contract period additional operational tests have been carried out. Because the air motion in the center of the chamber could only be observed on the video monitor once the cloud formed, the question of chamber turbulance prior to cloud formation still remained unanswered. It was therefore decided to use 2.02 micron diameter latex spheres in a dry chamber to observe air currents in the chamber in the absence of condensation. Initial studies employed a simple profile in which there was an initial 15 second period, during which the temperature and pressure were held at their initial values, while a complete set of chamber data was taken. A segment of sine wave with a 20 second period was then used to "roll off" into a 5°C/min cooling ramp; this was then followed by another sine wave segment which rolled out into a constant temperature and pressure mode at the final temperature. Chamber temperature ranged from 20°C to 10.3°C.

Observation of the motion of the latex spheres after the chamber was sealed and held at a constant temperature and pressure showed a general decrease. After (at most) 10 minutes, motion in the central observation volume (which is a horizontal cylinder appromately 1 cm in diameter by 3 cn long defined by the length of laser beam visible to the video monitor) had slowed to speeds of mm's/sec or less. The direction of motion while being somewhat random does show a preference for either right to left or bottom to top with occasional periods of zero motion. Several checks were made to insure that the presence of the high energy laser (1 watt beam energy) was not inducing the motion. This was done by comparing motion with the laser beam continuously in the chamber compared to that when the beam was blocked except for those short periods when observations were actually being made. No difference could be observed in the two cases.

Observation of the latex spheres during an expansion revealed motions which could very easily be correlated with chamber operation. Due to the size of the total computer control program it has been divided into four separate programs, each of which is automatically called by its predecessor. One transition point occurs between the stilling period and the actual expansion, and even though active control of the wall temperature is maintained during the program transition, the pressure control seals the chamber for a period of 5-10 seconds during that transition. Observation of the latex spheres during and immediately following this period showed no change in motion. As the expansion proceeded a downward motion of the particles began peaking at a speed of 2-3 cm/s then gradually decreasing to motion similar to that observed prior to the start of the expansion. Later an upward motion began again peaking at a speed of 2-3 cm/s followed by a decrease to the initial levels of motion. Several expansions with the same control profile and initial conditions were carried out with repeatable results. During these expansions it was possible to show that the downward motion began approximately eight seconds after the start of the actual wall cooling and corresponded to the peak in the error (mismatch) of the actual wall temperature (due to the thermal inertia of the wall during the inital transition) compared to the desired wall temperature . At this time the actual wall temperature is in fact higher than that desired. Since the gas temperature is controlled by the expansion which has virtually zero time lag, the gas temperature corresponds very closely to the desired temperature. Thus the temperature mismatch results in a warming of the gas near the wall resulting in a large single convection cell with the warmed gas at the wall rising and the return downdraft appearing in the center of the chamber.

The later updraft corresponds to the actual wall temperature overshooting the desired temperature profile and decreasing below the gas temperature. The lower wall temperature causes a cooling of the gas near the wall with a resulting downdraft at the walls and a return updraft in the center of the chamber as observed.

The sensitivity of the gas motion to mismatches between actual wall and gas temperatures makes it imperative to decrease both the maximum and average error between the gas and wall temperatures. Four wall thermometers were selected to be read at one second intervals in addition to the normal reading of all the thermometers at less frequent intervals. A post expansion program was developed to average the four thermometers and then a linear extrapolation was used to determine an effective actual chamber temperature at each of the 1001 times corresponding to a point in the control profile. The actual chamber temperature is then compared to the desired profile wall temperature and the error determined. The error is then used to correct the profile temperature at a point 5 seconds before the error actually occurred. In this way an anticipation capability is built into the control profile to compensate for the large thermal inertia of the wall. After the initial correction to the original profile the new profile is used to operate the chamber and a new set of data taken and the correction procedure repeated. After the third iteration the resulting errors are normally less than 0.07°C for the peak error and 0.04°C for the RMS error.

When the chamber is operated using a corrected control profile it is impossible to correlate any changes in the motion of the latex spheres due to any cooling of expansion activity of the chamber. Motion type and levels remain virtually constant throughout an expansion with cooling rates as high as 10°C/min.

Wet Runs - Once the profile correction procedure had been developed and tested on the dry chamber it was decided to mix the latex spheres with a wet NaCl aerosol sample to observe motion during the beginning of the cloud formation. We first attempted to use a NaCl concentration of 500 CCN/cm^3; however after two expansions in which the observed cloud density was estimated to be several times the aerosol input concentration, additional measurements of the total aerosol concentration were made using samples taken from the chamber just prior to closing. It was discovered that the atomizer used to disperse the latex sphere solution was also producing sufficient CCN to result in concentration of 2000 CCN/cm^3 in the chamber! Once the true concentration of CCN was known the observed particle motion in the chamber during the expansion could be explained.

Since the addition of a significant volume of air of unknown vapor content occurred when the latex spheres were added to the sample, our knowledge of the total sample vapor content was not adequate to attempt a realistic numerical modeling of the expansion. Therefore a dry adiabatic profile was used with the understanding that any condensation would produce latent heat which had not been accounted for, and hence an updraft in the central viewing volume was to be expected. The question of interest was: when would this begin relative to the time of cloud formation?

Motion of the latex spheres followed the same pattern as in the dry adiabatic expansions until the relative humidity approached 100%, at which time an upward motion started in the central viewing volume and gradually increased in speed until cloud formation when there was a sudden additional increase in speed. The relative humidity as a function of time was estimated after the fact using the cloud formation as a reference point. A crude calculation of the warming effect due to the latent heat released by a concentration of 2500 CCN/cm^3 growing through the haze region indicates that this could very well be tne driving force for the observed pre-cloud motion of the spheres.

It is our current belief that most of the motion observed in the chamber during the wet NaCl cloud-forming expansions can be attributed to differences in the aerosol concentration assumed in the numerical cloud model to generate the initial control profile and the concentration of aerosol actually in the chamber when the expansion is performed. It is felt that we are currently underestimating both aerosol and cloud drop concentrations. Additional calibration work is planned for the aerosol measurements. Cloud drop concentrations at present are visual estimates made from the video monitor. A family of control profiles having the same temperature profile but varying the assumed aerosol concentration have been generated and corrected for thermal inertia. This will permit the appropriate profile to be entered after the actual aerosol concentration in the chamber has been measured.

ROMULUS CHAMBER MECHANICAL CONSTRUCTION

During the first year of work we made a final evaluation of the cost trade-offs involved in use of an outside vendor for the major machine work verses having the work done in the University's central machine shop. The second choice had the advantage of being able to maintain close day to day supervision of the work and provide immediate response to any questions or problems. However it had the disadvantage of requiring upgrading of the central shops capabilities to include a milling machine large enough to handle the side wall heat sink cylinders, a gun drill for the cylinder fluid cooling passages, and a CNC milling machine for the large number of repetitive machining operations involved.

Early in the year an extensive search was made to locate an external machine shop able and willing to accept the project. While one or two shops were located they either refused to give a firm total cost which University purchasing regulations require or the cost given was prohibitively high compared to the projected in-house cost. During the latter part of the first year the decision to do the machine work in-house was finalized and steps taken to acquire the equipment required to upgrade the University central machine shop and provide the necessary capabilities. Full capabilities were not achieved until well into the second year of work.

Early in the second year building modifications required for the Romulus chamber were completed. These included replacing a section of the floor with an isolated reinforced concrete pad as a foundation for the chamber and a set of trap doors in the ceiling to permit its assembly to full height.

During the latter half of the second year design and construction of the molds for casting the cooling and expansion manifolds for the Romulus chamber was completed and prototype manifolds were available for testing. During this same period machining was started on the top and bottom heat sinks for the Romulus chamber.

During the third year machine work on the top and bottom section heat sinks was completed and lapping for the TEM surface finished. With the completion of the upgrading of the central machine shop, machining work on the large cylinders for the side wall heat sinks could be started and by the end of the year all nine had been machined to shape except for the final surfacing of the bottom end. Gun drilling of the long vertical cooling passages had also been completed and the location of both the top and bottom of each hole checked to determine drift. Of the 864 holes only one hole on each of 6 cylinders had drifted far enough to require correction. In each case the location of the hole was at the edge of the weld left by the rolling and welding of the original plates to form the cylinders. Four of the cylinder required shifting one vertical column of inner wall plate stud holes 0.25 inches toward the center of the affected flat and the other two required one corner studhole to be drilled at a 5°

angle to the surface normal. At this point the individual inner wall plates had only been machined to size and surfaced to thickness so a small set was set aside to be drilled with a stud pattern for the four modified cylinder flats; a single plate design fit all four flats. With these changes, drilling could proceed for the stud thread inserts. This was the last step before laminating the two component pieces together to form the composite corner wall plate. The lamination was done with student labor and consequently averaged only 3-4 plates per week, but this was still rapid enough so that other work was not held up (even though work continued into the fourth year). After the temperature uniformity tests on the inner wall plates of Proto II were completed, the design for the Romulus chamber was tested. As the design explicitly incorporated the concept of associating an equal mass of inner wall plate with each TEM under the plate, there was no need to level the plate edges as was done in the Proto II chamber.

Work continued on the support equipment. The ceiling hoist was constructed and installed in the aerosol laboratory. It can be moved over the trap doors directly above the chamber location, and is used to lower the assembled chamber sections into position. At the same time design and location of the four service columns next to the chamber were finalized. These columns are located at 90° intervals around the chamber and contain the TEM power leads, transistor thermometer cables, secondary cooling fluid supply and return lines, and the external lines for the expansion and sample flush system. In addition the eight-bit digital control valve for the expansion systems was specified and a vendor located (our previous supplier no longer makes this type of valve).

Tests of the prototype manifolds were completed and production started. This also was a long term task performed primarily by student labor. Work proceeded simultaneously on parts for both cooling and expansion systems.

Approximately half of the TEM's for the Romulus chamber were grouped and prewired into sets ready for assembly as the inner wall plates and heat sinks were completed.

During the fourth year machine shop work on the nine side wall heat sink cylinders was completed, and assembly of the inner wall plates and TEM sets to the heat sinks started. Construction of the cast parts for both the cooling and expansion manifolds was completed. The digital valve for the expansion system was received and tested. The service columns including both the secondary cooling and expansion-sample flush systems were completed as far as possible without the chamber actually in position.

A discrete element computer model of the heat transfer within the chamber heat sinks and the proposed secondary cooling system was devised. The model permitted programming various time-temperature profiles for the chamber walls to simulated various experimental runs. This permitted a determination of the heat flow through the heat sink, transfer to the secondary cooling fluid, and its removal by the proposed two phase refrigeration system. These computer simulations were necessary to establish the final design parameters for the secondary cooling system. Initial estimates of compressor size ranged from a minimum of 10 tons corresponding to chamber cooling from room temperature to 0°C in one hour (with zero power to the TEM's), to a maximum of 100 tons corresponding to full power with immediate rejection of excess heat. The lower limit was obviously too small for practical use and the upper limit was both prohibitively expensive and inefficient since the heat could not be transferred through the fluid loop fast enough to utilize the full cooling capabilities of that large a compressor. Studies of a number of different simulated experiments showed that a 20 ton compressor combined with a 500 gal fluid reservoir provide the best combination. Flexibility was further enhanced if the reservoir could be isolated from the primary fluid loop, precooled and then cut into the loop after the sample was in the chamber and the chamber sealed. Once the overall design was established, work proceeded on the detailed design of the reservoirs and refrigeration system. (The degree of control flexibility precluded purchasing an off the shelf control system for the surplus 20 ton compressor that was on hand.)

Early in the fifth year machining and anodizing of the major chamber components was completed. Assembly of the inner wall plates and TEM sets to the heat sinks was completed for both the top and bottom sections and five of the side wall cylinders. All of the chamber manifolding was ready. The necessary parts had been installed on the top and bottom sections and three of the cylinders which also had the inner wall plates. At this point the top and bottom sections and the three completed cylinders were assembled in position, constituting a minimum height chamber. This configuration encompassed the entire range of connections and seals associated with a full seven cylinder configuration, but was much easier to work on.

With a minimum chamber in place the secondary cooling fluid loop could be completed and tested. Initial tests disclosed the usual leaks expected in this size system, but these were easily sealed. The expansion and sample flush system was also completed and tested once the pressure transducer and expansion valves were installed. At this point a minor problem occurred in that there initially were a sufficient number of leaks in the system that our normal gas leak detection procedures could not isolate their locations with enough resolution to permit effective repair. The problem was finally solved by filling the interior of the chamber and the expansion-sample flush system with water. This procedure was very effective in locating the leaks and showing their relative size. Once the system was sealed the chamber was drained and connected to a vacuum pump for a period of several weeks to insure removal of any residual water. Tests of the pressure transducer system and expansion system were then continued.

Construction of the secondary cooling refrigeration system was completed during the final six months to the point where manual control of the reservoir and circulation loop cooling is possible. A relatively simple automated control has been designed, and is awaiting construction.

OPTICAL SYSTEMS

Near the end of the first year and the beginning of the second year sufficient detail about the mechanical dimensions of the Romulus chamber had been established to permit detail specification of an optical table. The optical system planned at that time required stable and vibration-free platform. Experience with the Proto I chamber indicated a massive table supported by pneumatic legs. The requirement that we reach at least three sides of the chamber led to a "U" shaped design. This permitted the location of the laser, other single source, or detector equipment on the base of the U, while the arms extend around the chamber to reach the windows on each side.

The Romulus chamber has sidewall sections 16 inches tall. Nine sections have been constructed and up to seven can be used at one time. Three of the sections are equipped with windows to permit optical access to the interior of the chamber, and the design allows these sections to be used in any of the lowest six positions. Thus provision has been made to mount optical systems at any of the lowest six levels. To accomplish this the optical support system consists of a vibration isolated table at the lowest level and a critically damped tower mounted on it to reach the other five levels.

Once the complexity of the engineering required to achieve critical damping for the table-tower combination became apparent an experienced outside supplier was sought. Mechanical and optical requirements were specified, and Newport Research Corporation designed and constructed the tower and table. The table includes four pneumatic legs for vibration isolation, and the tower consists of six vertical columns with horizontal cross pieces which can be adjusted vertically in one inch increments.

To provide maintenance or repair access to the Romulus chamber, a system was developed to move the assembled table and tower with the optics in place. This consists of a steel plate under the pneumatic legs and a set of screw jacks which can lift plate, table and tower off the floor and a set of low profile air casters to be slipped under the plate at the leg locations. The entire assembly can then rest on the air casters away from the chamber. After the completion of the work the table is repositioned and the process reversed to remove the air casters. The entire operation can be safely performed by two workers.

The table and tower were received during the latter half of the second year and assembled in an out of the way corner of the simulation laboratory. This permitted testing of the table and tower and provided a location for work on other optical systems which were being developed and tested.

By the beginning of the second year work on the design of the Romulus side wall heat sinks had proceeded to the point that maximum permissible sizes for the viewing windows (based on minimizing the uncooled wall area) had been developed. Several designs were considered, but the only one which showed any promise was that making use of a double pane window with a thermostated fluid or gas circulated through the space between the two panes to provide temperature control. Sapphire windows were selected for their very high heat conductivity.

Problems associated with the fluid design included choice of a fluid with acceptable optical and thermal properties. It had to provide temperature control and at the same time permit undistorted chamber observation during flow. In addition limitations were put on its design by the conflicting criteria that the hole thru the heat sink be small enough (1.28 inch diameter) to retain the thermal integrity of the heat sink, and at the same time provide as large a viewing cross-section as possible (1 inch diameter). The main fluid flow problems dealt with providing reliable seals and insuring proper flow in the space between the panes so the inner pane would cool uniformly.

Work continued on these problems until a prototype window was successfully tested during the third year. Despite successful testing the design proved unsatisfactory. Its soldered brass construction, which required metalizing the edges of the sapphire windows, was not practical for the 15 to 18 windows planned. Moreover the use of 15 to 18 closed circulation loops containing flammable ethanol constituted a fire hazard. Therefore alternative designs and materials were sought.

During the fourth year a modified design was developed using nested Delrin cylinders with the window facing the inner chamber volume glued into the outer cylinder. A switch to gas (carbon dioxide) as the heat transfer medium reduced the sealing requirements placed on the fluid circuit and eliminated the fire hazard. Three new windoes were constructed and tested on the Proto II chamber.

During the second year the laser doppler drop sizing system on the Proto I chamber was reviewed. Detailed evaluation of the multi-step analysis of the signal (required to convolute the scattering intensity vs. frequency data into number of particles vs. particle size) revealed a complex propagation of the initial signal errors. Particularly confusing was the effect of the nonlinear nonmonotonic dependence of scattering efficiency on particle size. Also the actual volume being sampled in Proto I was significantly smaller than originally estimated due to restrictions imposed by coherence volume requirements. Finally the entire technique rested on the assumption of a quiescent condition in the chamber during the experiment; experience with the Proto I chamber indicated that this would be a very restrictive requirement. We therefore investigated other techniques for determining the drop size spectrum.

In examining various techniques it became clear that no one technique could be used for all experiments, and that the size distribution measurement technique should be tailored to individual experiments.

During the fourth year the feasibility of using holographic techniques was examined. While initially promising, detailed evaluation of the resolution achievable at the distances required by the chambers showed minimum practical resolution in the 10 micron range which is too large. Also the size of the required view ports to increase the resolution was not compatible with existing chamber designs. Finally the cost was prohibitive for a system with no guarantee of success.

A 90° laser scattering technique was also evaluated. The intensity of monochromatic light scattered from a drop is a complex rapidly varying function of drop size. However if the four strongest lines from an argon ion laser are used simultaneously and the scattering observed at 90°, the scattered light from a drop can be described as a linear function of the drop size (with a superimposed noise component). This noise has the undesirable effect of initiating an uncertainty in the determination of the drop radius, as large as $\pm$ 1 micron. Our plan is to focus the (four line) beam onto the spot in the chamber to be sampled (normally the center). Using a commercial scanning mirror, we will scan in the x and y directions, and translate the focus in the z direction. At the same time the scattered light at 90° would be focused on a slot whose projected size at the center of the scanned volume would equal the focused length of the beam, this would limit the system to light from the narrowest portion of the beam and define the size of this scanned volume. Light passing through the slot would be detected by a photomultiplier tube. A single position of the detection slot will work for an entire x-y scan, however as the focus point is moved in the z direction, movement of the location of the slot will be suitably sychronized. The technique has the advantages of operating at a distance, using a simple pulse height analysis, and operating with slowly moving or quiescent drops. The major disadvantage of the technique is the low (single measurement) accuracy of the radius ($\pm$ 1 micron). However improvement in this "error" should result from statistical analyses of multiple measurements.

During the final six months the final decision to utilize the four line 90° scattering system as a primary drop size spectrum system was made. Once this decision was made the detailed design of the mounts for the optical systems were completed and sent to the machine shop for fabrication. The final design had been delayed in order to coordinate the various systems: drop size spectrum, photographic, transmission and 4° Mie scattering. All systems either enter the chamber through the same window or use the same window for observation. At present all required hardware has been ordered.

SWITCHING POWER SUPPLIES

Design of the Romulus chamber called for the interior surface to be divided into 208 separate control areas, each cooled by 20 TEM's connected in series. The nominal resistance of the TEM's is 0.25 OHMS each (5 OHMS total). The maximum cooling current a thermoelectric module can sustain is 14 amps. This leads to a requirement for 208 programmable power supplies capable of $\pm$ 70 VDC at 14 amps. Or, an output power of 980 watts per unit plus line loss and overhead. Investigation of external suppliers revealed the cost of suitable commercial units to be prohibitive, therefore it was decided to design and build the special purpose unit in-house.

During the first year an evaluation was made of analog versus switching technology for the basic power supply design. While the analog technology is well known and straight-forward in approach it has an efficiency of only 40% when half power is delivered to the load. This meant that the full chamber using 100 kw to cool the walls would require approximately 150 kw of waste heat to be rejected by the power supplies. The switching technology while newer and subject to high frequency noise problems has a more uniform efficiency of approximately 85% at all output levels and presents a much smaller waste heat rejection problem. The higher power requirements of the linear supply would have required the installation of an additional building power transformer. This additional transformer would not be required with the switching supply. Also the switching supply required only half the floor space of the linear supply. On the basis of projected efficiencies, space requirements, building power availability, and other related considerations, the decision was made in favor of the switching technology. Development of the power supply design was the initiated.

By the first half of the second year various aspects of the power supply design were undergoing breadboard testing. The basic layout of the physical mounting was developed. This consists of two power supplies built as a single unit. The high power components are mounted on two commercial water cooled heat sinks connected end to end by their water inlet-outlet lines. The low power components for both power supplies are mounted on a single printed circuit board. The printed circuit board is attached to the heat sinks by hinged metal stand offs, and the entire assembly can be inserted as a unit into the mounting rack.

As the input voltage requirements were finalized plans for the step down power transforers could be developed. For safety reasons it was decided to break the incoming power into several parallel circuits which could be turned on or off as needed when the number of cylinders used for the chamber was varied. This approoach suggested the natural division of one transformer for each major chamber section. One transformer each for the top and bottom sections and one each for the seven sidewall sections. A rated power of 35 kVA also placed them in a size range which could be handled and mounted in the available space. Detailed requirements for the 3 phase 208 VAC to 90 VAC transformers were developed and a supplier located to design and build nine transformers. Along with the transformer design, plans were made to connect a separate entrance panel to the existing building power transformer to handle the increased load.

As layout of the Proto II chamber developed consideration was also given to its power requirements. Two alternatives were considered. The first was to make the two systems totally independent, however this would mean building 68 more power supplies and purchasing three more transformers. Also even at this early stage it was becoming obvious that available building space could become critical if care was not exercised. The second alternative was to utilize 68 of the power supplies used for the Romulus chamber to power the Proto II chamber. This approach is feasible since there are a sufficient number of other areas where the two chambers utilize the same equipment that it is unlikely that both chambers would be run at the same time. Therefore a switching circuit to permit a single control to change both the power and control lines of 68 power supplies from one chamber to the other was designed during the latter half of the second year.

During this period, construction of the power supplies themselves started and by the end of the second year there were enough heat sink sections completed for enough the Proto II chamber. Work was still being pursued on the design and layout of the printed circuit board.

Design of the printed circuit boards was completed midway through the third year and prototype boards received from the vendor. The prototype boards were assembled with already completed heat sink sections and tested for function and endurance. At this point one ring of side wall heat sink for the Proto II chamber had been complete and one inner wall plate was installed and connected to the prototype power supply. A very simple control circuit was built which caused the power supply to cool the inner wall plate at full power for 10 minutes. Then reverse the polarity and heat the inner wall plate back to 39°C. The polarity was again reversed and the cycle repeated. The system was operated for a total of approximately 6000 cycles with the only failure being the early burn out of several TEM's at the corners of the plate. This was traced to insufficient clamping force on the TEM's in these areas and additional studs were added to the plate and heat sink design. The low end of the temperature cycle was approximately -10°C. After successful testing of the prototype several minor modifications were made and the remainder of the boards ordered. During this same period the power transformers were received and the cabinet designed to house them. The same cabinet was also designed to house the 18 three phase water cooled rectifier assemblies to convert the incoming AC power to the $\pm$ 90 VDC required as input for the switching power supplies. The cabinet also contained the 18 large air cooled filter inductors used to prevent the high frequency noise generated by the switching power supplies from feeding into the AC power network. Once the rectifiers and inductors had been constructed the entire system was mounted in the enclosed steel cabinet. When the university physical plant personnel completed work on the power entrance panel, and the lines to the transformers installed, the system was successfully tested.

At the same time the transformers were being installed work was proceeding on the cabinets and mounts for the power supplies. A number of heavy duty aluminum electronics racks had been obtained through surplus and five of these were stripped and modified to house the switching power supplies. They were chosen because of the high power densities involved and to help suppress EMI. Modification included mounting a grid of aluminum guides so that the individual units could be slid in and out from the front of the cabinet. Adaptors were provided to connect to both the conduit containing the power cables coming from the transformers and the wireways going to the chambers. Copper buss bars were installed to distribute the incoming power and holes were cut in the back plate for the supply and return lines to the water cooled heat sinks. After modification the cabinets were set in place, and the conduit, wireways, and cooling system installed. The switch circuitry to control the 68 common power supplies (used for both the Proto II chamber and the Romulus chamber) was completed and mounted on the side of one of the power supply cabinets. Control leads to the Proto II analog controller cabinet were laid in and power cables run to the Proto II chamber.

During the fourth year power cables were run to the Romulus chamber. Construction of forty of the power supplies was completed and an additional forty printed circuit boards were assembled.

As the fifth year began the Proto II chamber was turned on and the first twenty of the double power supply units were placed in operation. Initial chamber tests revealed control instabilities which had to be corrected. Those problems traced to the power supplies were corrected on all available units in addition to those actually in use. By the end of the fifth year 49 of the 120 units had been completely assembled and given final testing. Both the heat sink and printed circuit boards for all 120 units are complete and the units are being joined and given final testing as they are needed.

After solution of the initial set of problems, operation of the power supplies with the Proto II chamber has been extremely reliable.

CONTROL AND DATA ACQUISITION COMPUTER

In the first year, in order to help determine the feasibility of using direct digital control for the Romulus chamber, an Electrical Engineering Master's candidate completed the design and simulation of a digital control algorithm suitable for the wall temperature control. The study showed the approach as feasible and provided parameters for a proportional controller with both integrator and derivative contributions.

By the third year the requirements placed on the system were sufficiently defined that the overall architecture for the computer system could be designed. The resulting design called for one host computer, for overall control and temperature data acquisition, with four slave computers to provide detail control and monitoring of the individual power supplies. A data link will provide communication between the NOVA 840 Master Computer and the host computer with the 840 maintaining overall system control. The design having been completed, the hardware could be specified and purchased. Once the items for a minimum system were received, the testing of the individual components was initiated. At approximately the same time the physical location of the computer hardware was finalized and the various cabling requirements specified.

By the fourth year the individual hardware components had been tested and were being assembled into an integrated system. In addition the basic operating system and the graphics software for informational display were tested. Hardware development was started with the design and breadboarding of the interface between the slave computers and the power supplies.

During the fifth year the host computer and its immediate peripherals were installed in their final location and brought up to operational status. The software to interface between the host computer and the four slave computers was developed by a computer science master's candidate as a library of subroutines which can be called from Fortran or assembly language. The subroutines were tested using one of the slave computers connected directly to the host computer. Development of the slave computer-power supply, interfaces with the D/A section and construction and testing of one of the four required boards was completed. The main printed circuit boards for the interfaces were designed and etched, and the DC-DC power converters for the slave computer were designed and the prototype successfully tested.

In the last six months the printed circuit boards for the slave computer power supplies were taped and etched and two of the four boards completed. The first of the four main slave computer-power supply interface boards was completed and tested. Basic communications software for the host-slave-power supply links were completed. All remaining parts, materials and equipment required to bring the system to full operation were ordered.

TRANSISTOR THERMOMETERS

At the beginning of the contract period the matter of the temperature measurement was regarded as settled. The transistor thermometer then being used with the Proto I chamber, as well as elsewhere in the Center, had been developed by Center personnel over a period of years and tests showed them to be acceptable in terms of stability, accuracy, and resolution. In addition they were cost effective, and computer and control compatible.

As work progressed on the Proto II chamber during the second year, the first set of transistors for new thermometer sensors was received. A series of tests were started to search for a potting compound which could be used to encapsulate the sensors without effecting their stability or other characteristics. Unfortunately, as the search proceeded, the test results indicated that the sensors did not appear to be stable in any of the materials tested.

At this time several of the new sensors were used in the temperature control system developed for our fast expansion chamber. When we tried to calibrate these sensors it was found that their calibration changed radically from day-to-day. After all other possible sources of drift had been eliminated the new sensors were replaced with some of the old style sensors, still on hand from Proto I. This cured the problem completely, and caused us to suspect the new sensors as the source of the other drift problems. A series of long term stability tests were initiated and the manufacturer contacted for additional manufacturing data.

It did not take very long for the stability tests to show that the new transistors in their current configuration did not have the required long term (or for that matter short term) stability . Discussions with the manufacturers were quite frustrating since they were extremely reluctant to discuss specific manufacturing processes with outsiders. It was finally determined that the die used for the original Proto I transistor had been changed and the surface was no longer being given a protective die coating prior to encapsulation. The removal of the coating permitted the migration of low level concentrations of impurities on the surface and, while they caused minimal effects on operating characteristics for normal commercial applications, the resulting changes in characteristics made them unusable as thermometer sensors.

Once the problem was isolated and defined a search for a new thermometer sensor and mounting configuration was started. The search was extremely time consuming due to the duration of the tests required to measure stability. Finally, later in the third year, a suitable transistor was located and a vendor found who would package the transistor in a hermetically sealed can. This effectively solved the impurity problem and provided a low thermal resistance mounting configuration. Work on assembling the sensors, attaching the electrical cable and mounting them in the small brass bodies continued into the fourth year.

Many of the noise suppression and control stability problems encountered and solved during the start-up of the Proto II chamber also provided solutions to the same problems which would have occurred with the Romulus chamber had they not been dealt with before-hand. Also during the fifth year cables from the electronics rack to the Romulus chamber for the 384 sensors (associated with the nine cylinders and the top and bottom sections) were laid in and plugs attached to both ends. Also the buss structure to interconnect the thermometer electronics output with the computer A/D controller was designed and integrated with the computer data format.

To date the printed circuit boards for the thermometry electronics have been ordered and the remainder of the A/D interface is being laid out in detail. All circuits have been electrically designed and all required parts and materials ordered.

SUMMARY

The Proto II chamber is currently operational and is being used in the 24 inch high configuration. The side wall ring for the second section has been assembled and is ready for installation. The response of the Proto II chamber to all tests so far performed has met or exceeded the design expectations.

While considerable time and effort were spent on development and construction of the Proto II chamber in most instances the same effort would have been required for the Romulus chamber. In most cases the application of the solutions developed for use with the Proto II chamber to the Romulus chamber have required few if any modifications beyond dimensional adjustments.

Romulus is to be operational in late Spring 1985. All major machine shop work is now complete; all mechanical parts are on-hand, and a three cylinder chamber has been assembled. All required parts and materials are either on-hand or due to be delivered shortly. We are now engaged in final development and construction of the control and data acquisition system and the transistor thermometers.

The scientific program, originally planned for the Proto I chamber, is now being pursued with Proto II.

REPORT OF INVENTIONS AND SUBCONTRACTS
(Pursuant to "Patent Rights" Contract Clause)

Form Approved
Budget Bureau No. 22-R160

INSTRUCTIONS TO CONTRACTOR

This form may be used for INTERIM and FINAL reports, and when used shall be completed and forwarded to the Contracting Officer in triplicate.

An INTERIM report shall be submitted at least every twelve months, commencing with the date of the contract, and should include only those inventions and subcontracts for which complete information has not previously been reported.

A FINAL report shall be submitted as soon as practicable after the work under the contract is complete and shall include (a) a summary of all inventions required by the contract to be reported, including all inventions previously reported and any inventions since the last INTERIM report; and (b) any required information for subcontracts which has not previously been reported.

1. NAME AND ADDRESS OF CONTRACTOR *(Include ZIP Code)*
University of Missouri-Rolla, Graduate Center for Cloud Physics Research, Rolla, MO 65401-0249

2. CONTRACT NUMBER
AFOSR F49620-80-C-0090

3. TYPE OF REPORT *(check one)*
☐ a. INTERIM ☐ b. FINAL

SECTION I - INVENTIONS *("Subject Inventions" required to be reported by the "Patent Rights" clause)*

4. INVENTION DATA *(check one)*

☒ a. THERE WERE NO INVENTIONS WHICH REASONABLY APPEAR TO BE PATENTABLE

☐ b. LISTED BELOW ARE INVENTIONS WHICH REASONABLY APPEAR TO BE PATENTABLE. ANY INVENTION DISCLOSURES WHICH HAVE NOT BEEN PREVIOUSLY SUBMITTED TO THE CONTRACTING OFFICER ARE ATTACHED TO THIS REPORT.

(i) NAME OF INVENTOR	(ii) TITLE OF INVENTION	(iii) PATENT APPLICATION SERIAL NUMBER AND CONTRACTOR'S DOCKET NO.	(iv) CONTRACTOR HAS FILED OR WILL FILE U.S. PATENT APPLICATION		(v) CONFIRMATORY LICENSE OR ASSIGNMENT HAS BEEN FORWARDED TO CONTRACTING OFFICER	
			YES	NO	YES	NO
Period ending December, 1984						

SECTION II - SUBCONTRACTS *(Containing a "Patent Rights" clause)*

5. LISTED BELOW IS INFORMATION REQUIRED BUT NOT PREVIOUSLY REPORTED FOR SUBCONTRACTS *(If not applicable, write "None")*

(i) NAME AND ADDRESS OF SUBCONTRACTOR *(Include ZIP Code)*	(ii) SUBCONTRACT NUMBER	(iii) DATE CLAUSE FURNISHED TO CONTRACTING OFFICER	(iv) DATE SUBCONTRACT COMPLETED
NONE			

SECTION III - CERTIFICATE

CONTRACTOR CERTIFIES THAT THIS REPORT OF INVENTIONS AND SUBCONTRACTS, INCLUDING ANY ATTACHMENTS, IS CORRECT TO THE BEST OF THE CONTRACTOR'S KNOWLEDGE AND BELIEF

DATE	NAME AND TITLE OF AUTHORIZED OFFICIAL *(Print or Type)*	SIGNATURE
3-1-85	Dr. Daniel R. White Research Associate Professor	Daniel R. White

CATEGORY	ROMULUS	PROTO II	SUBTOTAL	TOTAL
E. ELECTRICAL				226,740.28
1. Power	16,653.69		16,653.69	
a. Entrance	16,553.56			
b. Distribution	100.13			
2. D.C. Power to Thermoelectric Modules	79,871.74	5,285.65	85,157.39	
a. Raw D.C.	22,011.79			
b. Switching p.s. development & testing	738.23	16.30		
c. Switching p.s. construction	51,094.35	171.47		
d. Power supply/computer interface	1,960.65			
e. Control network	984.83	4,228.72		
f. Power supply/chamber distribution	3,081.89	869.16		
3. Thermometry	90,744.95	948.93	91,693.88	
a. Sensor development & testing	987.50			
b. Sensor acquisition & fabrication	5,728.57	327.46		
c. Sensor calibration	26,792.77	36.85		
d. Thermometer elec. circuit constr.	31,561.69	584.62		
e. Temperature data acquisition system	25,674.42			
4. Stock - Electrical	14,534.86	17.30	14,552.16	
a. Material	4,004.56	6.98		
b. Parts	9,881.24	10.32		
c. Tools	649.06			
5. Diagnostic & Maintenance Equipment	15,565.28		15,565.28	
6. Maintenance	3,117.88		3,117.88	
a. Repair	1,442.94			
b. Preventive				
c. Housekeeping	1,674.94			

C. COMPUTER				41,039.10
1. Control & Data Acquisition System	38,376.50	94.24	38,470.74	
a. Control computer & equipment	31,353.27	24.72		
b. Control interface; bus structure dev.	2,711.64	69.52		
c. Software development	3,914.18			
d. Hardware maintenance	397.41			
2. Analysis	2,562.66	5.70	2,568.36	
a. Computer & peripheral equipment	738.03	5.70		
b. Interfacing	404.85			
c. Software development	1,419.78			
O. OPTICAL SYSTEMS				88,081.21
1. Optical Table & Tower	43,922.92	120.71	44,043.63	
a. Design				
b. Equipment acquisition	43,605.49	9.03		
c. Fabrication of accessories	317.43	69.80		
d. Assembly		41.88		
2. Doppler & Mie Scattering Systems	16,407.22	171.96	16,579.18	
a. Design	84.91			
b. Equipment acquisition	15,037.24	106.54		
c. Fabrication of accessories	253.84	15.34		
d. Assembly	6.86			
e. Testing	456.87	50.08		
f. Maintenance & Repair	567.50			
3. Photographic System	5,933.53	21.97	5,955.50	
a. Design				
b. Equipment acquisition	5,861.27	21.97		

c. Fabrication of accessories				
d. Assembly				
e. Testing				
f. Supplies	76.26			
4. Transmission System	10,407.45		10,407.45	
a. Design				
b. Equipment acquisition	10,407.45			
c. Fabrication of accessories				
d. Assembly				
e. Testing				
5. Scanning Drop Sizer	11,095.45		11,095.45	
a. Design				
b. Equipment acquisition	5,975.45			
c. Fabrication of accessories	5,120.00			
M. MECHANICAL				232,911.20
1. Top & Bottom Heat Sinks	5,062.26	4,825.58	9,887.84	
a. Surfacing & sides	1,738.20	1,257.00		
b. Deep hole drilling	480.00	1,050.44		
c. Short hole drilling & tapping	1,894.26	2,374.34		
d. Lapping surfaces	886.44	143.80		
e. Metal acquisition	59.36			
f. Design & drawings	4.00			
2. Side Wall Heat Sinks	39,232.40	14,347.24	53,579.64	
a. Outside flats	6,442.95	7,055.29		
b. Inside flats	4,476.07			
c. Size length of cylinder	5,914.10			
d. Gun drill deep holes	2,700.66	240.00		
e. Fabrication of fixtures	2,919.73	5.53		

f. Short hole drilling	11,819.23	3,044.50	
g. Complete end machining	3,149.65	695.30	
h. Metal acquisition	343.58	2,362.91	
i. Design & drawings	12.00	6.25	
j. Anodizing	1,454.43	937.46	
3. Inner Wall Plates	20,895.21	3,726.67	24,621.88
a. Surfacing	8,936.40		
b. Drilling	6,471.16	2,045.70	
c. Gluing	1,097.59	2.65	
d. Metal & supplies acquisition	3,111.82	345.28	
e. Testing	1,278.24	1,166.04	
f. Anodizing		167.00	
4. Hoist	2,515.47	2,003.90	4,519.37
5. Gaskets	1,124.30	996.47	2,120.77
a. Molding	9.13	49.90	
b. Fixtures	79.11	183.00	
c. Supplies & equipment	528.86	763.57	
d. Design	507.20		
6. Cooling Manifolds	6,310.36	1,887.01	8,197.37
a. Molding	221.13	35.38	
b. Fixtures & forms	1,263.96	679.20	
c. Assembly & mounting on chamber	295.68	269.70	
d. Supply & equipment	4,513.59	902.73	
e. Design & testing	16.00		
7. Base Stand for Chamber	823.86	55.80	879.66
a. Fabrication	821.86	38.00	
b. Supplies & equipment	2.00	17.80	

8. Observation Windows	4,510.83	1,474.96	5,985.79
a. Development & testing	245.06		
b. Machining	3,011.98	1,464.50	
c. Assembly	2.75		
d. Equipment or component acquisition	1,251.04	10.46	
9. Thermoelectric Control Panel Assembly	6,448.40	1,710.58	8,158.98
a. T.E. sizing	1,473.66		
b. Soldering T.E. strings	459.73		
c. Assembly		6.15	
d. Supply & equipment acquisition	4,515.01	1,704.43	
10. Thermoelectric Control Panel Testing			
11. Secondary Cooling System	15,136.21	64.36	15,200.57
a. Design		1.50	
b. Construction	3,559.37	50.94	
c. Testing			
d. Supply & equipment acquisition	11,576.84	11.92	
12. Aerosol Inlet System	1,653.33	2,068.48	3,721.81
a. Design			
b. Construction	942.00	1,081.25	
c. Testing	29.10		
d. Supplies & equipment	682.23	987.23	
13. Expansion Manifolds	3,564.61	294.68	3,859.29
a. Molding	16.24		
b. Fixtures & forms	202.50		
c. Assembly & mounting on chamber	265.67		
d. Supply & equipment acquisition	3,080.20	294.68	
14. Overall Expansion System	8,036.17	20.99	8,057.16
a. Design	44.09		

b. Fabrication	57.34		
c. Assembly	120.09	3.22	
d. Testing			
e. Supply & equipment acquisition	7,814.65	17.77	
15. Assembly of Chamber Subsections	1,188.49	430.38	1,618.87
16. Pressure Tranducer		61.34	61.34
17. Storage Dollies	85.70	274.77	360.47
a. Fabrication		222.79	
b. Supplies & equipment	85.70	51.98	
18. Thermoelectric Module Acquisition	52,730.41	6,284.59	59,015.00
19. Building Modifications	2,994.22		2,994.22
a. Planning & design			
b. Materials & supplies	394.29		
c. Labor or subcontracts	2,599.93		
20. Sample & Air Lines	1,525.97	2.03	1,528.00
a. Fittings & valves	513.19	2.03	
b. Materials & supplies	1,012.78		
c. Assembly			
21. Stock Items	8,457.08	25.70	8,482.78
a. Materials	5,789.03	20.20	
b. Parts	1,055.86		
c. Tools	1,612.19	5.50	
22. Clean Room	337.41		337.41
a. Parts	337.41		
b. Construction			
23. Humidifier	1,254.16	10.82	1,264.98
a. Parts	1,252.87	10.82	
b. Assembly	1.29		

24. CFD	6,025.17		6,025.17	
a. Parts	2,037.33			
b. Machining	3,870.12			
c. Assembly	58.31			
d. Design & testing	59.41			
25. Service Columns	684.68		684.68	
a. Parts	684.68			
b. Design				
26. Maintenance	621.06	24.17	645.23	
a. Repair	584.93	10.80		
b. Preventive		13.37		
c. Housekeeping	36.13			
27. TEM Vacuum System	234.73		234.73	
a. Parts & materials	234.73			
b. Assembly				
28. Electrostatic Classifiers	517.71		517.71	
a. Parts & materials	517.71			
b. Construction				
c. Testing				
29. Aerosol Generation	350.48		350.48	
a. Parts & materials	350.48			
b. Construction				
ADMINISTRATIVE	7,424.47		7,424.47	7,424.47
BLUEPRINTS	79.75		79.75	79.75
GRAND TOTALS	549,019.03	47,256.98		596,276.01

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